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[HEAT LOSSES AND EFFICIENCIES OF OTTO GAS ENGINE]

NEEL & SHAW

Heat Losses and Efficiencies of Otto Gas Engine.

Percy L. Neel.
Alex. W. Shaw.

Neel & Shaw '97
A Otto Gas Engine.
75

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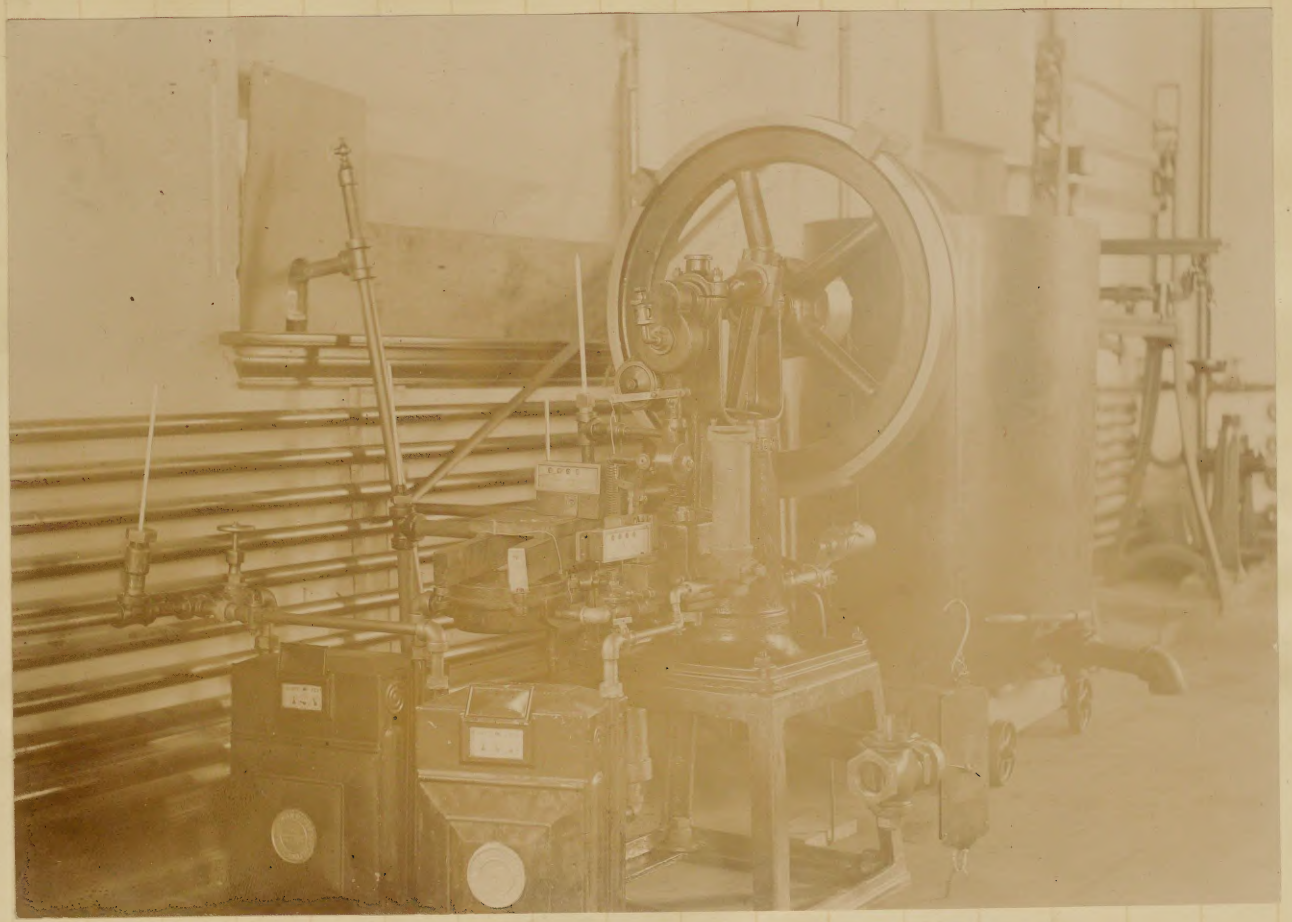


Test of a One-Third Horse Power Otto Gas Engine.

The following [illegible] of tests of a one-third horse power (nominal rating) Otto Gas Engine manufactured by the "Otto Gas Engine Co." 33rd and Thirst Sts. Philadelphia.

The tests were made in the Mechanical laboratory of the University of Pennsylvania. The first one on March 16th, ran for one hundred and thirty minutes, while the second and third tests for one hundred and twenty minutes each were taken on March 18th.

The engine was run at different speeds and loads, and the object of the tests was to determine the

test which is to find the [illegible]

A description of the engine and the apparatus used in making the test is given on page 20, and in the following description, the letters and numbers refer to the [illegible]

The engine consists of a vertical cylinder 3 inches in diameter with a trunk piston, which is connected to a cranked shaft (1) by means of a connecting-rod (2), and having a five inch stroke. On one end of the shaft is a fly wheel 10 inches in diameter, and on the other a gear wheel which gears into another having twice the number of teeth. This second gear wheel has an eccentric on its shaft which operates the rod (22), which in turn

Mantles rise without lose valve (w) and the exhaust (x). (The gas passes exhaust is seen in the photograph but are enclosed in the casing (y).) The pipe (z) is the admission of gas to the chamber V, where the gas is stored before being admitted with air to the cylinder by the lose valve W, which is lifted by cam (a) every other stroke of the piston.

The governor itself consists of a round, threaded weight (R) on the end of a lever having a screw thread and a lock nut, so that the position of the weight can be changed. The fulcrum is at (g) and the further end of the lever is held by a spring (f), the pivot at (e) forming part of the valve rod (22). Projecting downward from the fulcrum is a small rod (h)

which is cast in one piece with the bell, and which carries a hook at its lower end. With the latter engages a projection on the stem of the valve (1), which is pressed against it by the spring. When the lateram moves upward with the rod (22), the valve is lifted and gas is admitted to the chamber V. When, however, the engine goes too fast the moment of inertia of the weight (21) when being suddenly lifted, causes that end of the lever to stay down for an instant. This causes the small rod (23) to slip out, and as the governor continues to rise, the hook misses the projection and consequently does not lift the valve. Since gas is not admitted and there not being any explosion the engine slows down until the moment

meter, the weight is sufficient for the spring to control, when the fork again hangs vertically and is in a position to raise the valve.

Gas is supplied to the engine from the meter (d) — connected to gas main — through the equalizing tee (f) and the tap (s), which is supplied with a graduated disc and pointer. Ignition takes place through the pipe (18).

The meter (e) supplies gas for a Bunsen-burner enclosed in the combustion cylinder (x), the amount of gas for this purpose being regulated by the cock (23). In this cylinder is a tube of small diameter closed at the top, and around the inner wall at a short distance from the tube there is a lining of asbestos. The flame from the burner plays about the small

tube and heats it red hot.

The air used by the engine is admitted through the pipe (U), which communicates with the space between the bottom end of the cylinder (C) and the base of the engine. From this space passages lead up to the valve (V). It is also admitted to the space above the piston through small holes in the engine's base.

A water-jacket surrounds the cylinder and valve box. The water enters the bottom of the jacket and circulates near the top through the pipe (J).

The slide valve (W) which admits air and gas to the cylinder is worked by a reversing motion. The back of the valve has small holes in it which communicate with the gas chamber (V).

The space under the disc communicates with the air passage. When the valve is lifted by the suction of the piston, a mixture of gas and air enters the cylinder, and since the area under the disc is much greater than the area of the little hole in the seat, the proportion of air to gas is quite large. This proportion can be regulated by a spring on the valve. By tightening the spring the proportion of air to gas is increased, and vice versa.

The engine works in what is known as an "Otto cycle". Starting with a charge of gas in the chamber (V) a mixture of gas and air is drawn into the cylinder through the valve (W) on the upward stroke of the piston. The valve (W) then closes and upon the second and downward stroke the mixture

is compressed in the hot tube which explodes it when the engine has reached the dead point. Expansion then occurs in the third stroke, and on the fourth and last, the exhaust valve (u) is opened by the rod (22), and the exhaust gases pass out into the atmosphere.

The gas for the next explosion enters the chamber (V) when the hook on the governor lifts the valve at (t) during the first or suction stroke.

It will thus be seen that there are four separate motions to the cycle and in order to fulfill them all each valve has to be operated in succession once in every four strokes. This is accomplished mechanically for the valves (t' and (u) by the gear wheels mentioned before. The valve (IV), operated by suction

takes care of itself.

The way in which the gas valves operate the valves through the rod (22) may be simply explained. The rod is actuated by an eccentric on the shaft of the worm gear wheel, which is making one revolution while the fly-wheel makes two, due to the worm having three times as many teeth as the one on the shaft of the engine, and as they both mesh, (as the 22) will be raised and lowered once in every four strokes of the piston. In the first stroke, the rod raises, (as the valve at (t), on the second it continues to rise, on the third it descends, and on the fourth and last of the cycle it ascends to its normal point closing (t) and opening the exhaust valve (u).

A description of the apparatus used

in making the tests given.

The brake employed to determine the brake horse power consisted of a steel rod (8) which acted on the rim of the fly-wheel, being held in position by wooden guides as at (9). A scale pan for weights was hung on one end of the cord and the other end was attached to the spring balance (7), which in turn was held by a hook (1) in the floor.

The indicated horse power was determined with a Thomson indicator (3), using a separator and also a hand planimeter for measuring diagrams. The indicator was attached to the pipe (24) which communicated with the upper part of the cylinder, the pipe being provided with a cock at (2). The cord (4) passed over one end to the floor, the necessary

hold the indicator steady.

To get the required motion for the drum (3), a string (12) was fastened to a pin projecting from the hub of the fly-wheel. The string was about nine inches long and had a loop at its lower end, the loop hanging about where the number 12 is, on the photograph. Another string (25), wound around the drum, had a hook on its free end. When the engine was running, the string (12) was flung out by centrifugal force and its free end could be caught and held in the hand, provided it was not so that there would be no up and down motion of the free end due to the eccentricity of the pin. When the string was thus held, the other string (25) could be hooked to it on the loop, and then upon letting go, the necessary

motion would be given to the drum (3) of the indicator.

To get the speed of the fly-wheel, a counter (m) was fixed so that it was worked by the valve rod (22). To do this; an iron rod (15) was clamped on (22) so that its outer end worked the counter by means of a wire having a hook at either end. Since the rod (22) goes up and down once in every two revolutions of the fly-wheel, the reading of the counter when multiplied by two will give the number of revolutions made by the wheel in a certain time.

In order to count the number of explosions the counter (n) was attached to the valve (t) which supplies gas. Whenever gas was admitted, the valve was lifted and so worked the counter.

The amount of gas admitted at

The diameter of the orifice was measured by the metal wire used in making the orifice. A thermometer (C) graduated into 1/10 degrees was used to measure the temperature of the water in the vessel. The thermometer (C) was fixed in an iron stand so that the bulb was just in the water. The temperature of the room was measured by a similar thermometer (D).

A Bunsen burner (not shown in the figure, but in readiness when (26)) supplied the flame of gas for the melting of the wax.

A thermometer (E) indicated the temperature of the room.

In order to keep the apparatus at a certain amount of water was allowed to flow through the jacket. The water

were united by a rule of three
fold. In the counter, K, and the
wind vane of the motor and motor-
counter, indicated the direction of
the water at mast and mast.

[illegible] of [illegible] in the [illegible]
the emitted into the tank (?) [illegible]
the [illegible], and the weight of the [illegible]
was determined by the scales (14) on which
the tank rested.

The test was [illegible] by [illegible] the
engine up to [illegible] speed on the
[illegible] and [illegible] the engine to run
for a short time in order to get every-
thing working in normal condition.

During the counter and dis-
counter was then taken by the [illegible]
ter, and the readings of the [illegible]
[illegible] [illegible] were and the
values at which the tank rested. The

the water and the volume of gas taken.

In the first test, the time was noted in which it took the hand on the two cubic feet dial, to make one revolution. This time, then divided into the whole time of the test and multiplied by two gave the amount of gas used, in cubic feet. This was done for both meters. In the second and third tests, however, the number of revolutions which the hand made was simply counted for each meter.

Samples of the exhaust gas were taken from the rock (9) and analyzed with the Elliot apparatus, and the analysis was made of the water gas taken for the run at the time of the tests. The Hempel pipette was employed in the latter analysis.

The mean relative humidity, for the

days on which the [illegible] obtained from the United States Mint Bureau at Philadelphia.

In setting a [illegible], to the nine-tenths point nearest to adjustment the setting on the next [illegible] the English would [illegible] but it was also noticed that a certain number of the tests gave better results than others on the same [illegible] and the best on the average was obtained. In fact by altering the tests, sometimes not enough, or too much, the sound could stop. The explanation of this is obvious. In order that there should be any emission at all, there must be a certain proportion — within limits — of air to gas. By adjusting the spring on the valve, there is a point is reached where the proportion

is within the limit and a trial must take place. This by adjusting the stop S, which regulates the gas, there is found a point where the amount of gas supplied is sufficient for the machine when the engine is at work at a certain speed and load.

After the test has been taken, the piston rod is connected to the engine and the cock of the cylinder determined by trial is then opened to the point where the bottom of the piston is, when the crank is on its upper dead point. The water used is first weighed in a can, then enough of it was poured into the cylinder to fill the desired volume. Then the weight of the can and water was again taken. The difference in weight gave the weight of water in the cylinder, and from this the volume was

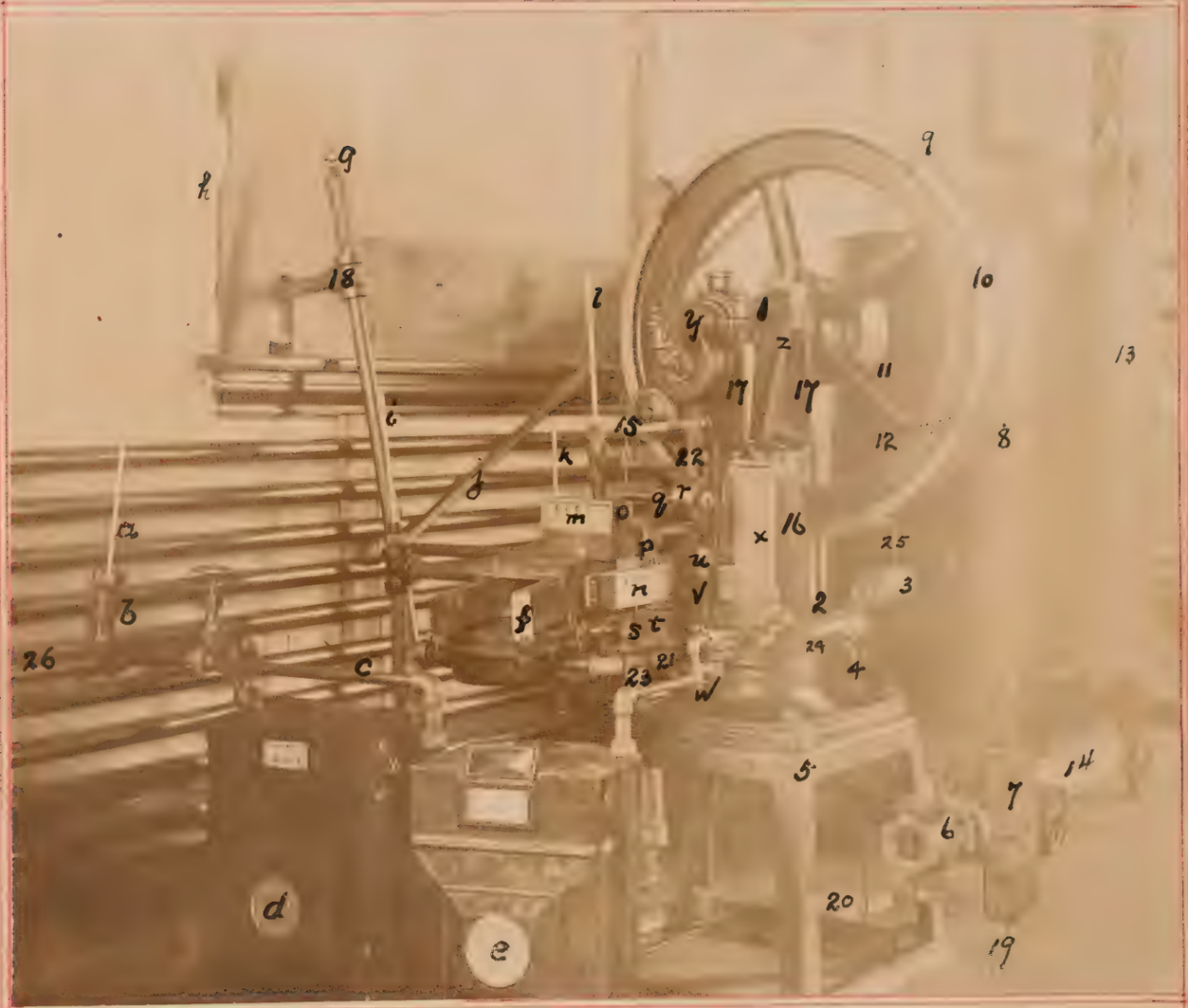
calculated. The clearance volume was determined by deducting the volume swept through by the piston from the whole volume of the cylinder.

To get the circumference of the fly-wheel (a meter was taken to center of brake arm) the rope used for the brake was wound around it and measured directly. The circumference = 6.29 feet.

Since it was noticed that the spring in the indicator worked freely and (being in communication with the cylinder for an instant only, every ten minutes) the calibration of the spring was made on the "Crosby Steam Gauge Tester". With a quarter sq. inch piston, it requires a force of 120.7 lbs. per sq. inch to compress it an inch. With a half a sq. inch piston, it takes just one half that force, or 60.35 lbs. per sq. inch.

Since the results of the second test were the best of the three, the data for that test will be used to calculate the various efficiencies and heat losses are calculated.

Picture of Engine and
Apparatus on inside
of Flap.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Readings — Test II.

TABLE 1.

TIME	Revolution Counter ($\frac{1}{2}$ revolutions)	Explosion Counter	Net Balance Reading	Scale Pan	Air Temp.	Gas Temperatures	
						INLET	EXHAUST
			lbs. oz.	lbs.	(Fahr.)	(Fahr.)	(Fahr.)
10.40	3580	3508	5 – 7 $\frac{1}{4}$	1.945	71.0	70.0	331.0
10.50	5444	4894	5 – 6 $\frac{1}{4}$	1.945	71.0	70.0	331.0
11.00	7327	5992	5 – 6 $\frac{1}{4}$	1.945	71.0	70.1	336.0
11.10	9208	7058	5 – 5 $\frac{1}{4}$	1.945	71.0	70.8	331.0
11.20	11092	8178	5 – 5 $\frac{1}{4}$	1.945	72.0	71.3	334.0
11.30	12957	9327	5 – 5 $\frac{1}{4}$	1.945	70.8	71.5	342.5
11.40	14813	10530	5 – 6 $\frac{1}{4}$	1.945	71.0	71.1	346.0
11.50	16666	11745	5 – 7 $\frac{1}{4}$	1.945	71.0	71.2	354.0
12.00	18515	12997	5 – 8 $\frac{1}{4}$	1.945	71.8	71.6	358.0
12.10	20362	14246	5 – 9 $\frac{1}{4}$	1.945	71.9	71.8	361.0
12.20	22207	15521	5 – 7 $\frac{1}{4}$	1.945	71.0	71.5	357.2
12.30	24052	16804	5 – 8 $\frac{1}{4}$	1.945	70.0	71.0	354.0
12.40	25894	18061	5 – 9 $\frac{1}{4}$	1.945	70.2	71.0	354.2
MEAN			5.438	1.945	71.05	71.0	345.4

Revolutions made by "2 cu. ft. hand" on meter (d), in 2 hrs = 14 $\frac{1}{4}$

∴ Gas used for explosions in 2 hrs = 14.25 × 2 = 28.5 cu. ft.

Tap (S) at division 4 $\frac{1}{2}$.

Readings.

TABLE 2.

TIME	Gas Pressure (inches water above atmos'e)	Weight of Jacket water	Temperatures of water	
			INLET (Fahr.)	OUTLET. (Fahr.)
10.40	3.8	166.50	76.0	200.0
10.50	3.8	169.25	77.0	204.0
11.00	3.8	173.00	77.0	196.0
11.10	3.8	177.00	78.0	197.0
11.20	3.8	178.00	79.0	202.2
11.30	3.8	184.00	78.0	195.0
11.40	3.8	190.00	73.0	190.0
11.50	3.8	195.00	70.0	184.0
12.00	3.8	198.50	72.0	183.0
12.10	3.8	203.50	74.0	182.5
12.20	3.8	208.00	74.2	186.0
12.30	3.8	210.50	74.0	190.0
12.40	3.8	218.75	74.0	195.0
TOTAL		52.25		
MEAN	3.8		75.1	192.6

Revolutions made by "2 cu. ft. hand" on meter (e) in 2 hrs = $4\frac{8}{10}$

∴ Gas used by burner in 2 hrs. = $4.8 \times 2 = 9.6$ cu. ft.

Exhaust Gas Analysis.

TABLE 3.

TIME	After KOH	After Pyro.	After $CuCl_2$
10.30	96.4	96.0	93.9
11.05	96.7	96.1	94.2
12.00	96.5	96.0	94.2
MEAN	96.53	96.03	94.1

Illuminating Gas Analysis.

TABLE 4.

Original volume	100.0	
after KOH	100.0	$CO_2 = 0.0$
" H_2SO_4	95.3	$C_2H_4 = 4.7$
" Pyro.	94.2	$O = 1.1$
" $CuCl_2$	87.2	$CO = 7.0$
Vol. residual gas used for explosion	12.0	
" after explosion	24.74	$CH_4 = 35.2$
" " KOH	19.9	
By calculation		$H = 49.6$
By difference		$N = 2.4$
TOTAL		100.0

Deduced from Table 1.

TABLE 5.

TIME	REVOLUTIONS PER MINUTE	EXPLOSIONS PER MINUTE
10.40		
	372.8	108.1
10.50		
	376.6	109.8
11.00		
	376.2	106.
11.10		
	376.8	112.0
11.20		
	373.0	115.1
11.30		
	371.2	120.1
11.40		
	370.6	121.5
11.50		
	369.8	125.2
12.00		
	369.4	124.4
12.10		
	369.0	127.5
12.20		
	369.0	128.3
12.30		
	368.4	125.7
12.40		
MEAN	371.85	118.8

Measurements from Indicator Cards.

TABLE 6.

CARD NO.	Area of WORK DIAGRAM	Length of card.	MEAN Effective Pressure = P_m	Area of Compression DIAGRAM	Suction in lbs.
	sq. in.	inches	lbs.	sq. in.	
15	1.50	3.69	24.40	0.48	2.55
16	1.50	3.71	24.30	0.41	2.55
17	1.60	3.73	25.75	0.40	2.57
18	1.80	3.68	29.30	0.32	2.56
19	1.72	3.72	27.70	0.31	2.57
20	2.00	3.69	32.50	0.36	2.57
21	1.76	3.70	28.60	0.40	2.56
22	1.70	3.69	27.65	0.45	2.55
23	2.07	3.70	33.60	———	2.56
24	1.92	3.73	31.10	0.45	2.56
25	1.84	3.72	29.70	0.45	2.57
26	1.80	3.70	29.20	0.45	2.56
27	1.80	3.71	29.20	0.34	2.56
MEAN	1.77	3.705	28.69	0.401	2.56

Mean pressure for compression stroke = $p_m = \frac{0.401 \times 60.35}{3.705} = 6.48$ lbs.

Measurements from Indicator Cards.

TABLE 7.

CARD NO.	Pressure at beginning of working stroke, in lbs.	Pressure at end of compression stroke lbs.
15	1.72 × 60.35	0.45 × 60.35
16	1.56 × 60.35	0.44 × 60.35
17	1.41 × 60.35	0.47 × 60.35
18	1.68 × 60.35	0.44 × 60.35
19	1.47 × 60.35	0.44 × 60.35
20	1.58 × 60.35	0.44 × 60.35
21	1.39 × 60.35	0.47 × 60.35
22	1.77 × 60.35	0.49 × 60.35
23	1.69 × 60.35	0.45 × 60.35
24	1.53 × 60.35	0.44 × 60.35
25	1.77 × 60.35	0.46 × 60.35
26	1.41 × 60.35	0.46 × 60.35
27	1.76 × 60.35	0.47 × 60.35
MEAN	1.59 × 60.35 = 96.258	0.455 × 60.35 = 27.459

NOTE — Pressures in lbs. per sq. inch, above atmosphere.

The calculations for the horse-power, heat losses and the various efficiencies, from the foregoing data are as follows:—

From Table 1, the mean effective pressure = 5.438 − 1.945 lbs. From Table 5 the mean revolutions per minute = 371.85. The circumference of the fly wheel, diameter to centre of belt, = 6.29 feet. Then

$$\text{Mean B.H.P.} = \frac{(5.438 - 1.945)\, 6.29 \times 371.85}{33\,000} = .2475$$

To get the mean indicated horse-power:— From Table 5, the mean explosions per minute = 118.8, and a mean effective pressure of 28.0 lbs. (5.438 − 1.945) Since an explosion did not always take place every fourth stroke, and since compression occurs whether an explosion takes place or not, the engine does a certain amount of internal work every time it misses an explosion; and this work has to be deducted from the work shown

by the diagram for the working stroke. The number of misses per minute equals half the revolutions per minute minus the number of explosions per minute, this equals $\frac{371.85}{2} - 118.8$

Then no explosion occurs the engine has acted on the previous (compression) stroke against a mean pressure of 6.48 lbs (Page 25) as determined from the cards. The diameter of the piston = 3 inches and the stroke = 5 inches. Therefore the

$$\text{Mean I.H.P.} = \frac{\left[(118.8 \times 28.69) - \left(\frac{371.85}{2} - 118.8\right) 6.48\right] \times 5 \times 3^2 \times .7854}{33\,000 \times 12} = .2785$$

$$\text{Mechanical Efficiency} = \frac{\text{B.H.P.}}{\text{I.H.P.}} = \frac{.2475}{.2785} = .888 = 88.8\%$$

$$\text{I.H.P.} - \text{B.H.P.} = .2785 - .2475 = .031 \text{ H.P.}$$

The gas used by the engine in two hours, without ignition, was 28.5 cubic feet (Page 21). Per hour this = 14.25 cu. ft. The gas used per B.H.P. per hour then $= \frac{14.25}{.2475} = 57.6$ cu. ft.

The gas used, without ignition, per I.H.P. per

hour = $\frac{14.25}{.2785}$ = 51.2 cu. ft.

The total amount of gas consumed, including ignition = 28.5 + 9.6 cu. ft. in two hours. This equals 38.1 cu. ft. Per hour it = 19.05 cu. ft.

Gas consumed per hour per B. H. P. including ignition = $\frac{19.05}{.2475}$ = 76.9 cu. ft.

Gas consumed per hour per I.H.P. including ignition = $\frac{19.05}{.2785}$ = 68.4 cu. ft.

In order to find the weight of gas used per explosion it is necessary to know R, which equals $C_p - C_v$ for a pound of the gas. R is gotten from the analysis of the illuminating gas (Table 4) in the following way.

	% vol.		wt.	% wt.
CO_2	= 0.0	× 12 =	0.0	0.00
C_2H_4	= 4.7	× 14 =	65.8	12.05
O	= 1.1	× 16 =	17.6	3.22
CO	= 7.0	× 14 =	98.0	17.94
CH_4	= 35.2	× 8 =	281.6	51.56
H	= 49.6	× 1 =	49.6	9.08
N	= 2.4	× 14 =	33.6	6.15
			546.2	100.00

The % weights are obtained by dividing each of the figures under column marked "wt." by the sum of that column, or 3546.2. Each % weight is then multiplied by the C_p for a pound of the corresponding gas. Then each % weight is multiplied by the C_v corresponding to it. The C_p and C_v for the various gases were found from Dugald Clerk Gas Engine, page 90.

	% wt. C_p	C_v
C_2H_4	$12.05 \times 0.404 = 4.868$	$12.05 \times 0.332 = 4.000$
O	$3.22 \times 0.217 = 0.699$	$3.22 \times 0.155 = 0.499$
CO	$17.94 \times 0.245 = 4.395$	$17.94 \times 0.173 = 3.105$
CH_4	$51.56 \times 0.593 = 30.550$	$51.56 \times 0.467 = 24.040$
H	$9.08 \times 3.409 = 30.950$	$9.08 \times 2.406 = 21.830$
N	$6.15 \times 0.244 = 1.500$	$6.15 \times 0.173 = 1.065$
	72.962	54.539

R for 100 cu. ft. = $72.962 - 54.539 = 18.423$ ft. lbs.

R for 1 cu. ft. of illuminating gas, in foot pounds, is:- $R = .1842 \times 778 = 143.3$

The pressure of the gas in the main = 4.7 + pressure of 3.8 inches of water (Table 2) minus the pressure of moisture in the gas. The gas was taken as half saturated, and since the mean temperature of gas in the main = 71°, the vapor pressure for that temperature taken from Peabody = .3726. ½ of saturated, this = .1863

The pressure of 3.8 inches of water = 3.8 X .0317 = .1375#

The pressure of the gas in the main then equals

14.7 + .1375 − .1863 = 14.651 lbs.

The specific volume of the gas in main = $\frac{RT}{P}$

$= \frac{143.3 \times (71+461)}{14.651 \times 144} = 36.14$ cu. ft. per lb.

The volume of gas in the main used per explosion

$= \frac{\text{cu. ft. per hr.}}{60 \times \text{no. of explosions per min.}} = \frac{14.25}{60 \times 118.8} = .001998$ cubic feet per exp.

The wt. of gas used per explosion then equals

$\frac{\text{cu. ft. per explosion}}{\text{vol. of 1 lb.}} = \frac{.001998}{36.14} = .0000553$ lbs.

To get the specific volume of the gas on admission to the cylinder:— The pressure here is 2.56 lbs. below the atmosphere (Table 6), and the temperature is taken as 5.4 degrees above the temperature of the outflowing jacket water, which has a mean value of 192.6 degrees (Table 2). Hence temperature of gas at inlet = 192.6 + 5.4 = 198 degrees.

The specific volume then = $\frac{143.3 \times (198+461)}{(14.7-2.56)\,144} = 54.02$ cu. ft. per lb.

The volume which the gas occupies after admission to the cylinder = cu. ft. per lb. × lbs. per explosion.

This equals $54.02 \times .000055\,45 = .002992$ cu. ft. per exp.

Now the whole volume of the cylinder minus the volume occupied by the gas per explosion will give the volume of air used per explosion.

Volume of cylinder + clearance = .0204 + .0105 = .03099 cu. ft.

The volume occupied by air therefore = .03099 − .00299 = .028 cu. ft. per explosion.

The specific volume of the air under the same

conditions of temperature and pressure, equals

$$\frac{53.37 \times (198+461)}{(14.7-2.56)\,144} = 20.12 \text{ cu. ft. per lb.}$$

The weight of air present $= \frac{\text{vol. of air per exp.}}{\text{vol. of 1 lb}} = \frac{.028}{20.12} = .00139$ lbs per exp.

Total wt. of gas + air = .0000554 + .00139 = .0014454 lbs. per exp.

Ratio of air to gas by volume $= \frac{.02800}{.00299} = 9.36$

Ratio of air to gas by weight $= \frac{.0013900}{.0000554} = 25.08$

As a check upon the above ratio (by weight) the weight of air to gas was obtained in another way from the analysis of the inlet and exhaust gases.

		% Vol.	% wt.
From TABLE 3	CO_2	3.47 × 22 = 76.34	5.34
	O	0.5 × 16 = 8.00	0.56
	CO	1.93 × 14 = 27.02	1.89
	N	94.1 × 14 = 1317.40	92.21
		1428.76	100.00

C in CO_2 of exhaust gas = $\frac{5.34 \times 12}{44}$ = 1.456

C in CO " " " = $\frac{1.89 \times 12}{28}$ = 0.8098

Total carbon in 100 lbs ex. gas = 2.2658

Nitrogen in 100 lbs " " = 92.21

C in C_2H_4 of inlet gas = $\frac{12.05 \times 24}{28}$ = 8.57

C in CO " " " = $\frac{17.94 \times 12}{28}$ = 7.68

C in CH_4 " " " = $\frac{51.56 \times 12}{16}$ = 38.62

Total carbon in 100 lbs. inlet gas = 54.87

Nitrogen " " " " " = 6.15

Now the N per lb. of $\frac{\text{carbon in}}{\text{inlet}}$ gas = $\frac{6.15}{54.87}$ = 0.1122

and " " " " " $\frac{\text{carbon in}}{\text{exhaust}}$ " = $\frac{92.21}{2.266}$ = 40.71

Then the N brought in by the air per pound carbon must be 40.71 − 0.112 = 40.598

The pounds of air per lb. carbon therefore = $\frac{40.598 \times 1446}{1078}$ = 54.46, since there are 1446 parts air by wt. to 1078 parts N by wt., gotten from $\frac{16 \times 23 + 14 \times 77}{14 \times 77} = \frac{1446}{1078}$

Now since there are 54.87 lbs. carbon in 100 lbs. inlet gas, and it has just been found that there

are 54.46 lbs. air per lb. carbon, then the weight of air per 100 lbs. gas = 54.46 × 54.87 = 2988 or the ratio of air by weight to 1 lb gas = 29.88

This value agrees very well with the ratio found before (on page 33), considering inaccuracies which are liable to occur in the analysis of the gases.

Temperature at end of compression. To get this temperature, we will have to know the R_1 — $C_p - C_v$ — for the mixture of air and gas — since we know the pressure from the cards and can find the volume per lb. of the mixture. Taking the ratio of air to gas by weight as 25.08 : 1, the per cent of air in mixture equals $\frac{25.08}{26.08} = 96.17\%$, and the per cent gas in mixture = $\frac{1}{26.08} = 3.83\%$

hence $R_1 = .9617 \times 53.37 + .0383 \times R$ (R for gas)

$\therefore R_1 = .9617 \times 53.37 + .0383 \times 143.3 = 51.37 + 5.48 = 56.85$

The volume of cylinder at end of compression stroke = clearance = .01054 cu. ft., and the

weight of gas and air in this volume = .0014454 lbs. (page 33).

Therefore $\frac{\text{clearance vol.}}{\text{wt. of gas and air}} = \frac{.0105^{-}4}{.0014454} = 6.95^{-}3$ cu. ft. per lb. of mixture.

The pressure at end of compression = $27.45^{-}9^{\#}$ (Table 7)

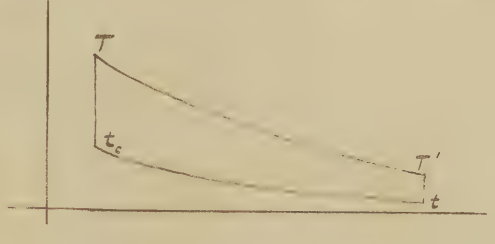
Now we have V, P and R_1

∴ Temperature at end of compression

$$= \frac{PV}{R_1} = \frac{(27.45^{-}9 + 14.7) \times 144 \times 6.95^{-}3}{5^{-}6.4 \, 5^{-}} = 742.5^{-}{}^{\circ}$$

or T (Fahrenheit) $= 742.5^{-} - 461 = 281.5^{-}{}^{\circ}$

The Maximum Theoretical Efficiency:—



The efficiency $E = \frac{C_v(T - t_c) - C_v(T' - t)}{C_v(T - t_c)}$

In both curves are adabatic and pass through the same volume change $\frac{T'}{T} = \frac{t}{t_c}$ so that

$$\frac{T'-t}{T-t_c} = \frac{T'}{T} = \frac{t}{t_c}$$

The efficiency may therefore be expressed

$$E = 1 - \frac{t}{t_c}$$

T = Temperature of mixture at inlet = 198° F. (page 32)

t_c = " " " " end of compression stroke, = 281.5° F (page 36)

Hence $E = 1 - \frac{198+461}{281.5+461} = .113 = 11.3\%$

Actual Heat Efficiency. This equals the ratio of the heat turned into work to the heat available.

The heat turned into work = $\frac{\text{I.H.P.} \times 33000}{\text{rev. per min.}}$

which = $\frac{.2785 \times 33000}{118.8} = 77.36$ foot lbs. per explosion.

$= \frac{77.36}{778} = .0994$ heat units.

To get the heat available, the calorific value of 1 lb. of inlet gas must first be obtained. This is gotten from the analysis

For the gas in the [illegible] :—

	% vol.	Wt. in unit vol.	Proportion by wt. in 1 lb. gas.	Calorific value per lb.	Calorific value in 1 lb. gas.
CH_4	35.2	2.816	.5156	23200	11962 B.T.U.
C_2H_4	4.7	0.658	.1205	21200	2555
H	49.6	0.496	.0908	52500	4767
CO	7.0	0.980	.1794	4300	771
N	2.4	0.336	.0915	~~0000~~	~~—~~
O	1.1	0.176	.0322	~~0000~~	~~—~~
	100.00	5.462	1.0000	Values in this col. taken from Dunkin p.365.	20055 B.T.U. in 1 lb. gas.

Heat available per explosion = lbs. gas per exp. × 20,055

or in ft. lbs. this is multiplied by 778.

∴ heat available = .00055 × 20055 × 778 = 864.4 ft. lbs. per exp.

In heat units this = $\frac{864.4}{778} = 1.11$

Hence actual heat efficiency = $\frac{\text{heat turned into work}}{\text{heat available}} = \frac{77.30}{864.4} = .0895$

= 8.95 %

The ratio of actual heat efficiency to maximum theoretical efficiency = $\frac{.0895}{.113} = .792 = 79.2$ %

Temperature at beginning of expansion stroke. This is the highest temperature, and is obtained as follows. Calling P', V' and T' the pressure volume and temperature at beginning of expansion stroke; and P, V and T the pressure, volume and temperature at end of compression stroke, we have

$$P'V' = R_1 T'$$

and $$PV = R_1 T$$

but $V' = V$ since these volumes are at same point of stroke

Hence $$\frac{P'}{P} = \frac{T'}{T}$$

$$\therefore T' = \frac{P'T}{P}$$

Now $T = 742.5^\circ$ absolute (Page 36)

and P' and P were gotten from the cards.

$P' = 96.258$ lbs. above atmosphere
$P = 27.459$ " " " } Table 7.

$$\therefore T' = \frac{(96.258 + 14.7) \times 742.5^\circ}{27.459 + 14.7} = 1954^\circ$$

Hence T' (Fahrenheit) $= 1954 - 461 = 1493^\circ$.

HEAT LOSSES.

Heat lost by Testing jacket water :- The water which passed through the jacket in two hours was 52.25 lbs. (Table 2), or $\frac{52.25}{24} = .44$ lbs. per minute. Its rise in temperature equals temp. at outlet − temp. at inlet.

Temp. at outlet = 192.6° F
Temp. at inlet = 75.1° F } Table 2.

The calories being 118.8 per minute, the heat lost through jacket water equals

$$\frac{.44 \times (192.6 - 75.1)}{118.8} = .4352 \text{ heat units per min.}$$

or $.4352 \times 778 = 338.6$ foot lbs per min.

Heat lost through exhaust. The heat carried off through the exhaust pipe is made up of several quantities. The sensible heat above a mixture entering the cylinder, that is brought in every time it enters

must be moisture and the mixture in the cylinder and in the air. The mixture is what is fired by the explosion. Immediately following the explosion, the water and moisture are turned into steam and superheated. This of course requires heat and comes from the heat carried out the exhaust.

Then the gases flow out, the amount of which depends on the weight of the gases and the temperature between inlet and exhaust. Gas, then must be taken into account in the mixture in the air and by the moisture in it. When we explode mixtures in cylinder, part is taken and is not admitted.

The part taken by the water formed by the explosion, the part taken by the moisture in the incoming gas, and the part

[illegible] (Page 29).

The weight of water formed by C_2H_4 in 100 lbs. gas $= \frac{4}{28} \times 12.05 \times \frac{18}{2}$

" " " " " $C H_4$ " " " " $= \frac{4}{16} \times 51.56 \times \frac{18}{2}$

" " " " " H " " " " $= 1 \times 9.08 \times \frac{18}{2}$

[illegible] the reason for the [illegible] calculations :- There is 12.05 lbs. C_2H_4 in 100 lbs. of illuminating gas. The weight of H in the $C_2H_4 = \frac{4}{24+4} \times 12.05$, since the atomic weights of C and H are 12 and 1 respectively. Having now the weight of hydrogen in the compound, we wish to know the weight of water which would result if this weight of H combined with O. Since the atomic weight of O = 16, then the equivalent water = H_2O = $\frac{16+2}{2}$ times weight of hydrogen, therefore the water formed $= \frac{4}{28} \times 12.05 \times \frac{18}{2}$ etc. The same reasoning applies to the other constituents which contain hydrogen.

The weight of water formed by the illuminating gas $= \frac{\left(\frac{4}{28} \times 12.05 + \frac{4}{16} \times 51.56 + 9.08\right)\frac{18}{2}}{100} = 2.1322$ lbs.

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Taking the ratio of air to gas by weight as 25.08 : 1, there must then be 26.08 lbs. of mixture per lb. of exhaust gas. Now we have found the weight of water formed by the expression to be 2.1322 lbs. Then lb. of gas, since 26.08 minus 2.1322 = the weight of exhaust gas per lb. of mixture.

The heat carried off by gas per minute equals (26.08 − 2.1322) × wt. of mixture per rev. × $C_p(T' - T'') = $ h.u. per rev., where C_p is the specific heat at constant volume for the exhaust gas, and T' = temperature of exhaust and T'' = temperature of gas before entrance to the cylinder. The C_p is gotten from the analysis of the exhaust gas and is as follows :—

	% vol		% wt.	C_p	
CO_2	3.47 × 22 =	76.34	5.34 × 0.216 =	1.137	
O —	0.5 × 16 =	8.00	0.56 × 0.217 =	0.122	
CO —	1.93 × 14 =	27.02	1.89 × 0.245 =	0.464	
N —	94.1 × 14 =	1317.40	92.21 × 0.244 =	22.510	
		1428.76	100.00	C_p = 24.233	(for mix.)

C_p for 1 lb. exhaust gas $\therefore$ = .24233

Temperature of exhaust = 345.4° F.
" " gas in main = 71.0° F } Table 1.

The heat carried off by exhaust gas, therefore

= (16.08 − 2.1322) × .0000554 × .24233 (345.4 − 71.0) = .08810 h.u. per exp.

The moisture contained in the gas, supposing it as one-half saturated = $\frac{1}{2} \times \frac{\text{Vol. 1 lb. gas}}{\text{Vol. 1 lb. steam at gas temp.}}$ = [illegible] lbs. per lb. of gas

The temp. of gas was 71° at inlet, and from Peabody the volume of 1 lb. steam at 71° = 857 cu. ft.

We already know the volume of 1 lb. of the gas, viz = 36.14 cubic ft. (see 31)

$\therefore$ moisture in gas at inlet = $\frac{36.14}{2 \times 857}$ = .02108 lbs. per cu. ft. gas.

The amount of moisture in the air equals

humidity × ratio by wt. of air to gas × vol. of 1 lb. air / vol. of 1 lb. steam at air temp.

Humidity = .67 (from [illegible] Table 3)

Temp. of air = 71.05° (Table 1)

Vol. of 1 lb. steam at 71.05° = 857 cu. ft. (2nd)

$$\therefore \text{moisture brought in by air} = \frac{.69 \times 25.08 \times \left[\frac{53.37\,(71.05+461)}{14.7 \times 144}\right]}{857}$$

$$= .2732 \text{ lbs. per cu. ft. gas.}$$

The total moisture at the exhaust then equals

- moisture left by expansion = 2.13220 lbs. per lb. gas
- moisture brought in by gas = 0.02108 " " " "
- " " " " air = 0.27320

2.42648 lbs. per cu. ft. gas.

since .000054 lbs. of gas are used per explosion,

the amount of water and moisture per explosion

$= 2.42648 \times .000054 = .001344$ lbs.

The amount of moisture brought in by the air per explosion when no expansion takes place

$$= \frac{\text{humidity} \times \text{vol. of cylinder}}{\text{vol. 1 lb. steam at air temp.}} \times \frac{\text{no. of misses}}{\text{no. of explosions}}$$

$$\text{Vol.} = \frac{.69 \times .02045 \times \left(\frac{371.85}{2} - 118.8\right)}{857 \times 118.8} = .0000091 \text{ cu. ft. per rev.}$$

where $\frac{371.85}{2}$ = half no. of revolutions, 118.8 = no. of [illegible] and .0204 cu. ft. = vol. of cylinder.

The amount of heat which the air or gas per explosion, when no explosions occur, gives

$$\frac{\text{vol. of cylinder}}{\text{vol. of 1 lb. air at int. temp.}} \times \frac{\text{no. of misses}}{\text{no. of explosions}} \times C_p \left(T_{\text{exhaust}} - T_{\text{entrance}}\right)$$

where C_v = C_v for air = $\frac{53.37}{.41 \times 778}$

$\therefore$ air carries off heat equal to $\frac{.02045}{\frac{53.37 \times (461 + 71.05)}{14.7 \times 144}} \times \frac{67.12}{118.8} \times \frac{53.37}{.41 \times 778}\left(345.4 - 71\right)$

$67.12 = \frac{371.85}{2} - 118.8$ = no. of misses

$= .03862$ h.u. per exp.

To this amount of water and moisture per explosion which is formed in the cylinder or goes through the cylinder, when equals

$.0001344 + .0000091 = .0001435$ lbs.

where .0001344 lbs is the water and moisture per exp. when

no explosions occur, and .0000091 lbs. is the moisture per explosion when no explosions take place.

The heat carried off by this water and moisture then equals :-

$$.0001435^{\#}\left(q_{212} + r_{212}\right) + .0001435^{\#} \times .48\left(T_{exhaust} - 212\right) - .0001435^{\#}\left(\text{Temp. air} - 32\right) \quad \text{per exp.}$$

where q and r for 212° are selected from Peabody. It will be noticed that the work expression includes not only the heat necessary to turn the water and moisture into steam but also the heat necessary to superheat it to the temperature of the exhaust, which is 345.4° F. (Table 1).

∴ heat carried off by water and moisture in exhaust =

$$= .0001435^{\#}\left(180.8 + 965.8\right) + .0001435^{\#} \times .48\left(345.4 - 212\right) - .0001435^{\#}\left(71 - 32\right)$$

$$= 0.16813 \text{ h. u. per explosion.}$$

The total heat going out the exhaust per explosion =

Heat carried off by exhaust gases proper = .08810 h. u.
" " " " air when no exp. occurs = .03862 " "
" " " " total water and moisture = .16813
TOTAL = 0.29485 h. u.

Heat Account

	B.T.U.	B.T.U.
Calorific value of gas per explosion	1.11	
Heat carried off by jacket water per exp.		0.43520
Heat per explosion actual work		0.09940
Heat carried off by exhaust gases proper		0.08810
" " " " air when no exp. occurs		0.03812
" " " " water formed per exp. and by moisture		0.16813
" " " " Radiation		0.28055
	1.11	1.11000

The radiation was obtained by subtracting the heat losses actually found from the calorific value of the gas per explosion.

The method of radiation is wrong in that the error in obtaining the temperature of the exhaust. The temperature as recorded by the thermometer in the exhaust pipe is lower than the actual temp. because when no explosions occurred, comparatively cool air was forced through the pipe. Hence temp obtained was a mean, which introduced an error

Readings — Test I.

TABLE 8.

TIME	Revolution Counter (½ revolutions)	Explosion Counter	Net Balance Reading	Scale Pan	Air Temp.	Gas Temperatures INLET	Gas Temperatures OUTLET
			lbs.	lbs.	(Fahr.)	(Fahr.)	(Fahr.)
2.40	6319	2415	6.4	1.75		58.0	357.0
2.50	83355	3648	6.4	1.75	57.7		360.0
3.00	10407	4921	6.5	1.75		58.0	364.0
3.10	12446	6315	6.5	1.75	60.0		374.0
3.20	14477	7705	6.6	1.75		59.0	377.9
3.30	16492	9144	6.6	1.75	60.1		381.0
3.40	18499	10620	6.6	1.75		60.0	390.0
3.50	20503	12034	6.6	1.75	61.0		382.0
4.00	22509	13441	6.6	1.75		60.2	384.0
4.10	24515	14836	6.6	1.75	60.0		388.0
4.20	26522	16317	6.6	1.75		61.2	391.0
4.30	28528	17761	6.6	1.75	63.0		387.0
4.40	30530	19156	6.75	1.75		64.0	384.4
4.50	32535	20506	6.75	1.75	62.2		378.7
MEAN			6.20	1.75	60.5	60.0	378.45

Mean time of 1 revolution of "2 cu. ft. hand" on meter (d) = 5 min. 19 sec.

∴ Gas used for explosions in 130 minutes = $\frac{130 \times 2}{5\frac{19}{60}} = 48.9$ cu. ft.

Jap (S) at division $4\frac{1}{2}$.

Readings

TABLE 9.

TIME	Gas Pressure (inches water above atmosphere)	Weight of Jacket Water	Temperatures of water	
			INLET	OUTLET
			(Fahr)	(Fahr.)
2.40	4.2	214	62.0	142.0
2.50	4.2	218	64.0	161.0
3.00	4.2	231	66.0	205.0
3.10	4.2	235	77.0	200.9
3.20	4.2	253	64.8	152.1
3.30	4.2	270	70.0	122.0
3.40	4.2	284	66.0	116.8
3.50	4.2	318	67.0	111.1
4.00	4.2	338	68.3	113.8
4.10	4.2	353	70.0	122.1
4.20	4.3	367	68.0	124.0
4.30	4.4	386	67.1	121.0
4.40	4.4	404	67.0	122.4
4.50	4.4	420	66.0	122.0
TOTAL		206		
MEAN	4.25		67.4	139.0

Mean time for one revolution of 2 in X. and on meter (e) = 15 min. 47 sec.

∴ Gas used in 130 minutes for the burner = $\frac{130 \times 2}{15 \frac{47}{60}} = 16.47$ cu. ft.

Exhaust Gas Analysis.

TABLE 10.

TIME	After KOH	After Pyro.	After $Cu Cl_2$
3.10	94.5	94.4	94.0
3.15	94.8	94.5	94.5
4.15	94.8	94.6	94.3
4.45	95.1	95.0	94.9
MEAN	94.8	94.625	94.425

Illuminating Gas Analysis.

TABLE 11.

Original volume	100.0	
after KOH	100.0	$CO_2 = 0.0$
" H_2SO_4	95.4	$C_2H_4 = 4.6$
" Pyro.	94.4	$O = 1.0$
" $Cu Cl_2$	87.2	$CO = 7.2$
Vol. residual gas used for explosion	12.0	
" after explosion	24.8	$CH_4 = 34.9$
" " KOH	20.0	
By calculation		$H = 50.3$
By difference		$N = 2.0$
TOTAL		100.0

Deduced from Table 8.

TABLE 12.

TIME	Revolutions PER MINUTE	Explosions PER MINUTE
2.40	407.2	123.3
2.50	410.4	127.3
3.00	407.8	139.4
3.10	406.2	139.0
3.20	403.0	143.9
3.30	401.4	147.6
3.40	400.8	141.4
3.50	400.3	140.7
4.00	401.2	139.5
4.10	401.4	148.1
4.20	401.2	144.4
4.30	400.4	139.5
4.40	401.0	145.0
4.50		
MEAN	403.3	139.2

Measurements from Indicator Cards.

TABLE 13.

CARD NO.	Area of Work Diagram	Length of card	Mean Effective Pressure = P_m	Area of compression Diagram	Suction lbs.
	sq. in.	inches	lbs.	Sq. in.	
1	0.92	3.62	30.65	0.2	2.0
2	0.90	3.67	29.68	0.2	2.0
3	0.93	3.63	30.16	0.2	2.0
4	0.93	3.65	30.75	0.2	2.0
5	0.92	3.67	30.15	0.2	2.0
6	0.85	3.62	28.34	0.2	2.2
7	0.89	3.64	29.55	0.2	2.1
8	0.91	3.67	29.55	0.2	1.7
9	1.00	3.61	33.40	0.2	1.8
10	0.85	3.62	28.34	0.2	2.0
11	0.82	3.64	27.12	0.2	1.9
12	0.92	3.62	30.65	0.2	2.0
13	1.00	3.61	33.40	0.2	2.0
14	1.00	3.64	33.15	0.2	2.1
MEAN	0.917	3.636	30.35	0.2	2.0

Mean pressure for compression stroke = $P_m = \frac{0.2 \times 120.7}{3.636} = 6.63$

Measurements from Indicator Cards.

TABLE 14.

CARD NO.	Pressure at beginning of working stroke, in lbs	Pressure at end of compression stroke in lbs.
1	1.09 X 120.7	0.25 X 120.7
2	1.12 X 120.7	0.24 X 120.7
3	1.14 X 120.7	0.24 X 120.7
4	1.08 X 120.7	0.23 X 120.7
5	1.09 X 120.7	0.24 X 120.7
6	1.16 X 120.7	0.25 X 120.7
7	1.16 X 120.7	0.25 X 120.7
8	1.06 X 120.7	0.23 X 120.7
9	1.18 X 120.7	0.24 X 120.7
10	1.01 X 120.7	0.25 X 120.7
11	1.03 X 120.7	0.25 X 120.7
12	0.97 X 120.7	0.24 X 120.7
13	1.08 X 120.7	0.24 X 120.7
14	1.14 X 120.7	0.24 X 120.7
MEAN	1.093 X 120.7 = 131.9	0.242 X 120.7 = 29.2094

NOTE:- Pressures in lbs. per sq. inch above Atmosphere.

Calculations. (Test I)

Mean B.H.P. $= \frac{(6.20 - 1.75) \times 6.29 \times 403.3}{33000} = 0.3394$

Mean I.H.P. $= \frac{[(30.35 \times 139.2) - (62.5 \times 6.63)] 5 \times 3^2 \times .7854}{33000 \times 12} = 0.3815$

Mechanical efficiency $= \frac{0.3394}{0.3815} = .889 = 88.9\%$

I.H.P. − B.H.P. $= .3815 - .3394 = 0.0421$ H.P.

Gas per B.H.P. per hour (without ignition) $= \frac{22.56}{0.3394} = 66.4$ cu. ft.

Gas per B.H.P. per hour (including ignition $= \frac{30.15}{0.3394} = 88.8$ cu. ft.

Gas per I.H.P. per hour (without ignition) $= \frac{22.56}{0.3815} = 59.1$ cu. ft.

Gas per I.H.P. per hour (including ignition) $= \frac{30.15}{0.3815} = 79.2$ cu. ft.

Total gas (main and ignition) per hour $= \frac{(48.9 + 16.47) \times 60}{130} = 30.15$ cu. ft.

gas per hour (without ignition) = $\frac{48.9 \times 60}{130}$ = 22.56 cu. ft.

Gas per hour (ignition) = $\frac{16.47 \times 60}{130}$ = 7.59 cu. ft.

	% Vol.		% wt.
CO_2	= 0.0 × 12 =	0.0	— 0.00
C_2H_4	= 4.6 × 14 =	64.4	— 11.90
CO	= 7.2 × 14 =	100.8	— 18.70
O	= 1.0 × 16 =	16.0	— 3.07
CH_4	= 34.9 × 8 =	279.2	— 51.80
H	= 50.3 × 1 =	50.3	— 9.33
N	= 2.0 × 14 =	28.0	— 5.20
		538.7	100.00

	% wt C_p		% wt C_v	
C_2H_4	11.9 × 0.404 =	4.810	11.9 × 0.332 =	3.950
CO	18.7 × 0.245 =	4.580	18.7 × 0.173 =	3.240
O	3.07 × 0.217 =	0.658	3.07 × 0.155 =	0.476
CH_4	51.8 × 0.593 =	30.700	51.8 × 0.467 =	24.290
H	9.33 × 3.409 =	31.870	9.33 × 2.406 =	22.490
N	5.20 × 0.244 =	1.270	5.20 × 0.173 =	0.899
		73.888		55.345

R for 100 lbs. $= 73.888 - 55.345 = 18.543$ ft. lbs.

R for one lb. $= 0.18543 \times 778 = 144.3$ (inlet gas)

Pressure of 4.25 in. water $= 4.25 \times .03617 = 0.153$

Specific volume of gas in main $= \dfrac{144.3 \times (60 + 461)}{(14.7 + 0.15 - 0.12)\,144} = 35.44$ cu. ft. per lb.

Volume of gas in main used per exp. $= \dfrac{48.9}{130 \times 139.2} = 0.002702$ cu. ft. per exp.

Weight of gas per exp. $= \dfrac{0.002702}{35.44} = 0.00007623$ lbs.

Specific vol. of gas after admission to cylinder $= \dfrac{144.3 \times (145 + 461)}{(14.7 - 2) \times 144}$

$= 47.82$ cu ft. per lb.

Vol. of gas after admission $= 47.82 \times 0.00007623 = 0.003645$ cu. ft. per exp.

Volume swept through by piston $= \dfrac{.7854 \times 3^2 \times 5}{144 \times 12} = 0.02045$ cu. ft.

Weight of water to fill total volume of cylinder

$= 9$ lbs. 4 oz $-$ 7 lb. 5 oz $= 1.937$ lbs.

Since a cubic foot of water weighs 62.5 lbs., the

volume swept through by piston plus clearance

$$= \frac{1.937}{62.5} = 0.03099 \text{ cu. ft.}$$

$\therefore$ $0.03099 - 0.02045 = 0.01054$ cu. ft. = vol. of clearance.

Vol. occupied by air $= 0.03099 - 0.003645 = 0.027345$ cu. ft.

The specific vol. of air $= \frac{53.37 \times (145 + 461)}{(14.7 - .2) \times 144} = 17.685$ cu. ft. per lb.

Weight of air $= \frac{0.027345}{17.685} = 0.0015462$ lbs. per exp.

Total wt. of gas + air $= 0.0015462 + 0.0000762 = 0.0016224$ lbs. per exp.

Ratio of air to gas by vol. $= \frac{0.027345}{0.003645} = 7.502$

Ratio of air to gas by wt. $= \frac{0.0015462}{0.0000762} = 20.29$

Temp. at end of compression $= \frac{PV}{R_1}$ where $R_1 = C_p - C_v$ for mixture of gas and air.

% air in mixture by wt. $= \frac{20.29}{21.29} = 95.3\%$

% gas in mixture by wt. $= \frac{1}{21.29} = 4.7\ \%$

$\therefore R_1 = 53.37 \times .953 + 144.3 \times .047 = 57.6$

Then temp. at end of compression $= \frac{(14.7 + 29.209) \times 144 \times 6.5}{57.6}$

$= 713.6^\circ$ Absolute

where $V = \frac{\text{Clearance}}{\text{wt. of gas and air}} = \frac{0.01054}{0.0016224} = 6.5$ cu. ft per lb.

Temp. (Fahrenheit) $= 713.6^\circ - 461^\circ = 252.6^\circ$ F.

Maximum theoretical efficiency $= 1 - \frac{145 + 461}{252.6 + 461} = 0.151$

$= 15.1\ \%$

	% Vol.	wt. in unit vol.	Proportion by wt. in one lb. gas.	Calorific value per pound.	Calorific value in one lb. gas.
CH_4	34.9	2.792	0.518	23200	12017 B.T.U.
C_2H_4	4.6	0.644	0.119	21200	2523 "
H	50.3	0.503	0.0933	52500	4898 "
CO	7.2	1.008	0.187	4300	804 "
N	2.0	0.28	0.052	———	000
O	1.0	0.16	0.0307	———	000
		5.387	1.0000		20,242 B.T.U.

Available energy per explosion in foot pounds

$= 0.0000763 \times 20,242 \times 778 = 1200.5$ ft. lbs.

Work done in foot lbs. per explosion

$= \frac{0.3815 \times 33000}{139.2} = 90.44$ ft. lbs.

Actual heat efficiency $= \frac{\text{work}}{\text{available energy}} = \frac{90.44}{1200.5} = 0.0753$

$= 7.53\%$

Ratio of actual heat efficiency to theoretical heat efficiency $= \frac{0.0753}{0.151} = 0.498 = 49.8\%$

Temperature at beginning of expansion stroke

$T' = \frac{P'T}{P} = \frac{(131.9 + 14.7)(252.6 + 461)}{(29.209 + 14.7)} = 2382°$ absolute

Temp. (Fahrenheit) $= 2382 - 461 = 1921°$

Heat lost by jacket water $= \frac{206\,(139 - 67.4) \times 778}{130 \times 139.2} = 634.3$ B.t.u. per exp.

$= \frac{634.3}{778} = 0.8153$ lb. m. p. exp.

Heat going out Exhaust :—

Weight of water formed by the explosion p.c. lb. of inlet gas

$$= \frac{\left[\left(\frac{4}{28} \times 11.9 + \frac{4}{16} \times 51.8 + 9.33\right) \frac{18}{2}\right]}{100} = 2.1582 \text{ lbs.}$$

	% vol		% wt	C_p	
CO_2	5.2 × 22	= 114.4	7.93 × 0.216	= 1.712	
O	0.20 × 14	= 2.8	0.19 × 0.217	= 0.041	
CO	0.175 × 16	= 2.8	0.19 × 0.245	= 0.046	
N	94.425 × 14	= 1322.8	91.69 × 0.244	= 22.391	
		1442.8	100.00		24.190

C_p (for 1 lb. exhaust gas) = .2419

21.29 − 2.1582 = 19.132 lbs. exhaust gas proper per lb. of inlet gas

Heat carried off by ex. gas proper

= 19.132 × 0.000762 × .2419 (378.45 − 60) = 0.1105 h.u. per cub. ft.

Moisture brought in by gas $\frac{1}{2} \times \frac{35.44}{1234} = 0.0143$ lbs. per lb. of gas.

Moisture brought in by air $= \frac{.94 \times 20.29 \left(\frac{53.37 \times (461 + 60.5)}{14.7 \times 144} \right)}{1213} = 0.1678$ lbs. per lb. of gas

Total water and moisture $= 2.1582 + 0.0143 + 0.1678 = 2.3403$ lbs. per lb. of gas.

Water and moisture per explosion $= 2.3403 \times 0.0000762 = 0.000175^6$ lbs.

Moisture brought in by air per explosion when no explosion takes place $= \frac{0.94 \times 0.02045^-}{1214} \times \frac{62.45^-}{139.2} = 0.000006962$ lbs.

Heat carried off by air per explosion when no explosion takes place

$= \left(\frac{0.02045^-}{13.131} \times \frac{62.45^-}{139.2} \right) \times 0.167 \times (378.5^- - 60.5^-) = 0.03635^-$ h.u. per exp.

Total water and moisture which is formed in cylinder or which goes through cylinder (including moisture when no explosions occur)

$= 0.000175^6 + 0.00000696 = 0.000182^56$ lbs. per exp.

Heat carried off by total water and moisture per explosion

$= 0.00018256(180.8 + 965.8) + 0.00018256 \times 48 \times (378.45 - 212)$

$- 0.00018256(60.5 - 32) = 0.2187013$ h. u. per exp.

Heat account.

	B.T.U.	B.T.U.
Calorific value of gas per explosion	1.54	
Heat carried off by jacket water per exp.		0.8153
Heat per explosion, actual work		0.1162
Heat carried off in exhaust gases proper		0.1105
" " " " air when no exp. occurs		0.0363
" " " " water formed per exp. and by moisture		0.2187
" " " " Radiation		0.2430
	1.54	1.5400

Readings — Test III.

TABLE 15.

TIME	Revolution counter ($\frac{1}{2}$ revolutions)	Explosion Counter	Net Balance Reading	Scale Pan	Air Temp.	Gas Temperatures INLET	Gas Temperatures OUTLET
			lbs. oz.	oz.	(Fahr.)	(Fahr.)	(Fahr.)
1.45	3927	3735	2 — 9 $\frac{1}{4}$	12.5	70.6	71.0	286.0
1.55	5857	4467	2 — 9 $\frac{1}{4}$	12.5	70.9	71.5	294.0
2.05	7786	5217	2 — 9 $\frac{1}{4}$	12.5	71.0	71.4	298.5
2.15	9715	6028	2 — 8 $\frac{1}{4}$	12.5	72.0	72.0	302.0
2.25	11641	6874	2 — 9 $\frac{1}{4}$	12.5	72.0	72.2	306.0
2.35	13571	7688	2 — 9 $\frac{1}{4}$	12.5	71.5	74.5	304.5
2.45	15499	8526	2 — 9 $\frac{1}{4}$	12.5	72.0	73.0	307.5
2.55	17428	9348	2 — 8 $\frac{1}{4}$	12.5	71.8	73.1	306.0
3.05	19355	10182	2 — 7 $\frac{1}{4}$	12.5	71.6	73.0	305.8
3.15	21283	11025	2 — 6 $\frac{1}{4}$	12.5	71.9	72.9	305.6
3.25	23209	11865	2 — 7 $\frac{1}{4}$	12.5	71.3	73.2	306.0
3.35	25136	12703	2 — 7 $\frac{1}{4}$	12.5	71.2	72.9	306.2
3.45	27064	13544	2 — 6 $\frac{1}{4}$	12.5	71.6	73.0	307.0
MEAN			2.510 lbs.	0.781 lbs.	71.5	72.6	302.7

Tap (5) at division $6\frac{1}{3}$.

Revolutions made by "2 cu. ft hand" on meter (d) in 2 hrs = 17.2

∴ for used for divisions in 2 hrs = 17.2 × 2 = 34.4 cu. ft.

Readings.

TABLE 16.

TIME	Gas Pressure (inches water above atmosphere)	Weight of Jacket Water	Temperatures of water.	
			INLET	OUTLET
			(Fahr.)	(Fahr.)
1.45	4.0	465.5	72.0	122.0
1.55	4.0	479.5	73.5	128.0
2.05	4.0	489.5	72.8	136.0
2.15	4.0	499.5	73.0	142.0
2.25	4.0	509.5	73.8	146.8
2.35	4.0	519.5	72.1	148.0
2.45	4.0	529.5	74.5	148.0
2.55	4.0	539.5	74.2	147.7
3.05	3.9	549.5	74.0	148.0
3.15	4.0	559.5	73.8	146.2
3.25	3.8	569.25	74.0	146.0
3.35	3.9	579.25	73.9	146.8
3.45	4.0	589.25	73.8	147.0
TOTAL		123.75		
MEAN	3.97		73.1	142.5

Revolutions made by "2 cu. ft. Sand" on meter (e) in 1 hr. = 4.5

∴ gas used by meter in 2 hrs = 4.5 × 2 = 9.0 cu. ft.

Exhaust Gas Analysis.

TABLE 17.

TIME	After KOH	After Pyro.	After $CuCl_2$
2.00	96.4	95.6	93.8
2.35	96.5	95.8	94.0
3.25	96.3	95.5	93.8
MEAN	96.4	95.63	93.87

Illuminating Gas Analysis.

TABLE 18.

Original volume	100.0	
after KOH	100.0	$CO_2 = 0.0$
" H_2SO_4	95.3	$C_2H_4 = 4.7$
" Pyro.	94.2	$O = 1.1$
" $Cu\,Cl_2$	87.2	$CO = 7.0$
Vol. residual gas used for explosion	12.0	
" after explosion	24.74	
" " KOH	19.9	$CH_4 = 35.2$
By calculation		$H = 49.6$
By difference		$N = 2.4$
TOTAL		100.0

Deduced from Table 15.

TABLE 19.

TIME	Revolutions per minute.	Explosions per minute.
1.45	386.0	73.2
1.55	385.8	75.0
2.05	385.8	81.1
2.15	385.2	84.6
2.25	384.0	81.4
2.35	385.6	83.8
2.45	385.8	82.2
2.55	385.4	83.7
3.05	385.6	84.3
3.15	385.2	84.0
3.25	384.4	83.8
3.35	385.6	84.1
3.45		
MEAN	385.51	81.54

Measurements from Indicator Cards.

TABLE 20.

CARD NO.	Area of work Diagram	Length of card	Mean Effective Pressure = P_m	Area of Compression Diagram	Suction lbs.
	sq. in.	inches	lbs.	Sq. in.	
28	1.2	3.70	38.8	0.24	2.41
29	1.1	3.71	35.6	0.23	2.41
30	1.1	3.72	35.2	0.23	2.41
31	0.9	3.65	29.4	0.22	2.41
32	1.0	3.70	32.4	0.22	2.88
33	0.94	3.62	31.2	0.23	2.41
34	0.95	3.64	31.3	0.23	2.41
35	0.90	3.64	29.7	0.22	3.01
36	0.70	3.64	23.1	0.18	3.01
37	0.87	3.64	23.1	0.20	2.41
38	0.90	3.64	29.1	0.20	2.41
39	0.74	3.69	24.0	0.22	2.41
40	0.70	3.64	23.1	0.20	2.41
MEAN		3.664	29.7	0.217	2.62

Mean pressure for compression stroke = $p_m = \frac{0.217 \times 120.7}{3.664} = 7.021$ lbs.

Measurements from Indicator Cards.

TABLE 21.

CARD NO.	Pressure at beginning of working stroke	Pressure at end of compression stroke
	lbs.	lbs.
28	1.16 × 120.7	0.24 × 120.7
29	1.25 × 120.7	0.22 × 120.7
30	1.60 × 120.7	0.22 × 120.7
31	1.68 × 120.7	0.24 × 120.7
32	1.51 × 120.7	0.21 × 120.7
33	1.60 × 120.7	0.21 × 120.7
34	1.69 × 120.7	0.21 × 120.7
35	1.60 × 120.7	0.21 × 120.7
36	1.55 × 120.7	0.21 × 120.7
37	1.53 × 120.7	0.20 × 120.7
38	1.54 × 120.7	0.20 × 120.7
39	1.64 × 120.7	0.21 × 120.7
40	1.62 × 120.7	0.20 × 120.7
MEAN	1.54 × 120.7 = 185.878	0.278 × 120.7 = 25.83

NOTE – Pressures in lbs. per sq. inch above atmosphere.

Calculations. (Test III.)

$$\text{Mean B. H. P.} = \frac{(2.510 - 0.781) \times 6.29 \times 385.61}{33\,000} = 0.12708$$

$$\text{Mean I. H. P.} = \frac{\left[(81.74 \times 29.7) - (192.8 - 81.74) \times 7.021\right] \times 5 \times 3^2 \times .7854}{33000 \times 12} = 0.147$$

$$\text{Mechanical Efficiency} = \frac{0.12708}{0.147} = .864 = 86.4\ \%$$

$$\text{I. H. P.} - \text{B. H. P.} = 0.147 - 0.12708 = 0.01992 \text{ H.P.}$$

$$\text{Gas per B. H. P. per hour, without ignition)} = \frac{17.2}{0.1271} = 135.4 \text{ cu. ft.}$$

$$\text{Gas per B. H. P. per hour (including ignition)} = \frac{21.7}{0.1271} = 170.8 \text{ cu. ft.}$$

$$\text{Gas per I. H. P. per hour (without ignition)} = \frac{17.2}{0.147} = 117 \text{ cu. ft.}$$

$$\text{Gas per I. H. P. per hour (including ignition)} = \frac{21.7}{0.147} = 147.7 \text{ cu. ft.}$$

$$\text{Total gas (main and ignition) per hour} = \frac{34.4 + 9.0}{2} = 21.7 \text{ cu. ft.}$$

Gas per hour without ignition) $= \frac{34.4}{2} = 17.2$ cu. ft.

Gas per hour (ignition) $= \frac{9}{2} = 4.5$ cu. ft.

	% vol.		% wt.
CO_2	$= 0.0 \times 12 =$	00.0	0.00
C_2H_4	$= 4.7 \times 14 =$	65.8	12.05
O	$= 1.1 \times 16 =$	17.6	3.22
CO	$= 7.0 \times 14 =$	98.0	17.94
CH_4	$= 35.2 \times 8 =$	281.6	51.56
H	$= 49.6 \times 1 =$	49.6	9.08
N	$= 2.4 \times 14 =$	33.6	6.15
		546.2	100.00

	% wt.	C_p		% wt.	C_v	
C_2H_4	12.05	× 0.404 =	4.868	12.05	× 0.332 =	4.000
O	3.22	× 0.217 =	0.699	3.22	× 0.155 =	0.499
CO	17.94	× 0.245 =	4.395	17.94	× 0.173 =	3.105
CH_4	51.56	× 0.593 =	30.550	51.56	× 0.467 =	24.040
H	9.08	× 3.409 =	30.950	9.08	× 2.406 =	21.830
N	6.15	× 0.244 =	1.500	6.15	× 0.173 =	1.065
			72.962			54.539

R for 100 lbs. = 72.962 − 54.539 = 18.423 h. u.

R for one lb. = .1842 × 778 = 143.3 ft. lbs. (inlet gas)

Pressure of 3.97 inches water = 3.97 × .03617 = .14 lbs.

Specific volume of gas in main = $\frac{143.3\,(72.6+461)}{(14.7+0.14-0.19)\times 144} = 36.21$ cu. ft. per lb.

Volume of gas in main used per exp. = $\frac{34.4}{120\times 81.74} = 0.003508$ cu. ft. per exp.

Weight of gas per exp. = $\frac{0.003508}{36.21} = 0.00009682$ lbs.

Specific volume of gas after admission to cylinder

$= \frac{143.3\,(148+461)}{(14.7-2.62)\times 144} = 50.09$ cu. ft. per lb.

Volume of gas after admission to cylinder

$= 0.00009682 \times 50.09 = 0.004855$ cu. ft.

Volume of cylinder + clearance = 0.03099 cu. ft.

∴ volume occupied by air = 0.03099 − 0.004855 = 0.02613 cu. ft.

The specific volume of air = $\frac{53.37 (178 + 461)}{(14.7 - 2.62) \times 144} = 18.64$ cu. ft. per lb.

Weight of air = $\frac{0.02613}{18.64} = 0.001404$ lbs. per cup.

Total wt. of gas + air = 0.000097 + 0.001404 = 0.001501 lbs.

Ratio of air to gas by vol. = $\frac{0.02613}{0.004855} = 5.381$

Ratio of air to gas by wt. = $\frac{0.001404}{0.00009682} = 14.71$

Temp. at end of compression = $\frac{PV}{R_1}$, where R_1 equals $C_p - C_v$ for mixture of gas and air.

% air in mixture by wt. = $\frac{14.49 \times 100}{15.49} = 93.56\%$

% gas in mixture by wt. = $\frac{1 \times 100}{15.49} = 6.44\%$

$\therefore R_1 = 53.37 \times .9356 + .1433 \times .0644 = 49.11$

Specific vol. of mixture at end of compression = $\frac{0.01054}{0.001501} = 0.997$ cu. ft. per lb.

Then temp. at end of compression = T

$$= \frac{(14.7 + 25.83) \times 144 \times 6.699}{51.11} = 661.5^\circ \text{ absolute}$$

Or temperature in Fahrenheit $= 661.5 - 461 = 200.5^\circ$ F.

Maximum Theoretical Efficiency $= 1 - \frac{461 + 178}{461 + 200.5} = .0794$

$= 7.94\ \%$

	% Vol	wt. in unit vol.	Proportion by weight in 1 lb. gas	Calorific value per lb.	Calorific value in one lb. gas.
CH_4	35.2	2.816	0.5156	23200	11962 B.T.U.
C_2H_4	4.7	0.658	0.1205	21200	2555 "
H	49.6	0.496	0.0908	52500	4767 "
CO	7.0	0.980	0.1794	4300	771 "
N	2.4	0.336	0.0615	~~0000~~	~~0000~~ "
O	1.1	0.176	0.0322	~~0000~~	~~0000~~ "
		5.462	1.0000		20055 B.T.U.

Available energy per explosion in foot lbs.

$= 0.0000768 \times 20055 \times 778 = 1510.6$ ft. lbs.

$= \frac{1510.6}{778} = 1.94$ h.p.

Ther. Eff.

actual work done in ft. lbs. per explosion

$$= \frac{0.147 \times 33000}{81.74} = 59.35 \text{ ft. lbs. per exp.}$$

$$= \frac{59.35}{778} = 0.0763 \text{ h. u. per exp.}$$

Actual Heat Efficiency $= \frac{\text{work}}{\text{available energy}} = \frac{59.35}{1510.6} = .0392$

$= 3.92\%$

Ratio of actual heat efficiency to theoretical eff. efficiency $= \frac{0.0392}{0.0794} = .494 = 49.4\%$.

Temperature at beginning of expansion stroke

$$T' = \frac{P'T}{P} = \frac{(185.878 + 14.7)(200.5 + 461)}{25.83 + 14.7} = 3273^\circ$$

abs. t

T' (Fahr. scale) $= 3273 - 461 = 2812^\circ$ F.

Heat lost by jacket water

$$= \frac{125.75(142.5 - 75.1) \times 778}{120 \times 81.74} = 681.2$$

ft. lbs. per exp.

$$= \frac{681.2}{778} = 0.8756 \text{ h. u. per exp.}$$

Heat lost through Exhaust.

Weight of water formed by the explosion per lb. of inlet gas $= \dfrac{\left(\frac{4}{28} \times 12.05 + \frac{4}{16} \times 51.56 + 9.08\right)\frac{18}{2}}{100} = 2.1322$ lbs.

	% vol.		% wt.	C_p
CO_2	$3.6 \times 22 =$	79.20	$5.54 \times 0.216 =$	1.197
O	$0.77 \times 16 =$	12.32	$0.86 \times 0.217 =$	0.186
CO	$1.76 \times 14 =$	24.64	$1.73 \times 0.245 =$	0.424
N	$93.87 \times 14 =$	1314.18	$91.87 \times 0.244 =$	22.420
		1430.34		24.227

C_p (for 1 lb. exhaust gas) $= 0.24227$

$15.49 - 2.132 = 13.358$ lbs. exhaust gas formed per lb. of inlet gas.

Heat carried off by exhaust gas per lb.

$= 13.358 \times 0.00009682 \times 0.24227 (302.7 - 72.6) = 0.07198$

h. u. per exp.

Moisture brought in by gas = $\frac{1}{2} \times \frac{36.21}{819}$ = 0.0222 lbs. per lb. of gas.

Moisture brought in by air = $\dfrac{0.69 \times 14.49 \left(\frac{53.37(461+71.5)}{14.7 \times 144} \right)}{843}$

= 0.1538 lbs. per lb. of gas.

Total water and moisture = 2.1322 + 0.0222 + 0.1538 = 2.3082 lbs. per lb. of gas.

Water and moisture per exp. = 2.3082 × 0.00009682 = 0.0002235 lbs.

Moisture brought in by the air per exp. when no explosion takes place = $\frac{.69 \times 0.02045}{843} \times \frac{111.1}{81.71}$ = 0.0002144 lbs.

Heat carried off by air per explosion when no exp. takes place = $\dfrac{0.02045}{\frac{53.37(461+71.5)}{14.7 \times 144}} \times \frac{111.1}{81.71} \times 0.167 (302.7 - 71.5)$

= 0.08025 h. u. per exp.

Total water and moisture which is formed in cylinder or which goes through cylinder (including

moisture when no explosions occur

$= 0.000024 + 0.0002235 = 0.0002447$ lbs per cu. ft.

Heat carried off by total water and moisture per explosion

$= 0.0002447(180.8 + 965.8) + 0.0002447 \times .48(302.7 - 212)$

$- 0.0002449(72.6 - 32) = 0.28152$ B. T. U.

Heat Account.

	B.T.U.	B.T.U.
Calorific value of gas per explosion	1.94	
Heat carried off by jacket water per exp..		0.8756
Heat per explosion, actual work		0.0763
Heat carried off by exhaust gases proper		0.0720
" " " " air when no. exps. occurs		0.0803
" " " " water formed by exp and by moisture		0.2815
" " " " Radiation		0.5543
	1.94	1.9400

The result of the test was that the efficiency of the engine was the greater the less the amount of water allowed to circulate through the jacket. That is more heat is turned into work, and less is carried off by the water.

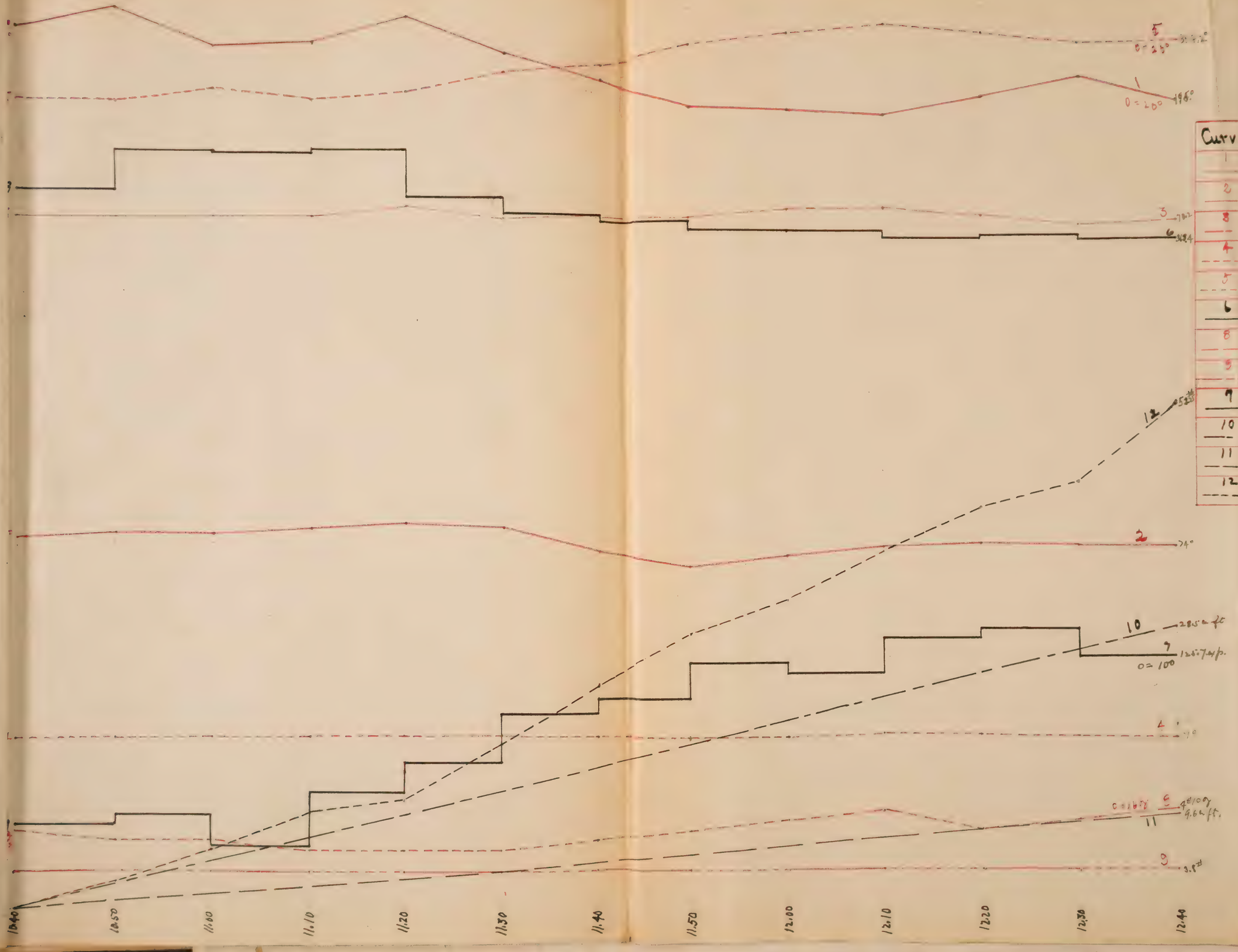
The results also show that the temperature of the exhaust is rather lower than what the temperature of the exhaust gas is, as it flows out the pipe. This is accounted for by the fact that the thermometer recorded the temperature of the exhaust pipe, which temperature is really a mean between the temperature of the exhausted gas after explosion and the temperature of the air which goes through the cylinder when no explosion takes place. Hence the more the number of explosions, the more the mean temperature will be, and consequently the larger the heat loss converted to radiation.

Test. No I.

Curve	Meaning	Scale
1	Temp. outflow water	2° = .1"
2	Temp. inflow water	.1" = 2°
3	Temp. air.	.1" = 1°
4	Temp. inflow gas	.1" = 4°
5	Temp. up. gas	.1" = 4°
6	revolutions per min.	.1" = 1 r.
7	explosions per min.	.1" = 1 e/p.
8	Scale reading #	.1" = 1#
9	manometer, inches water	.1" = 1"
10	Cu ft gas used (exp.)	.1" = 1 c. ft
11	" " " (burner)	.1" = 1 c. ft
12	Th water used	.1" = 2 lbs

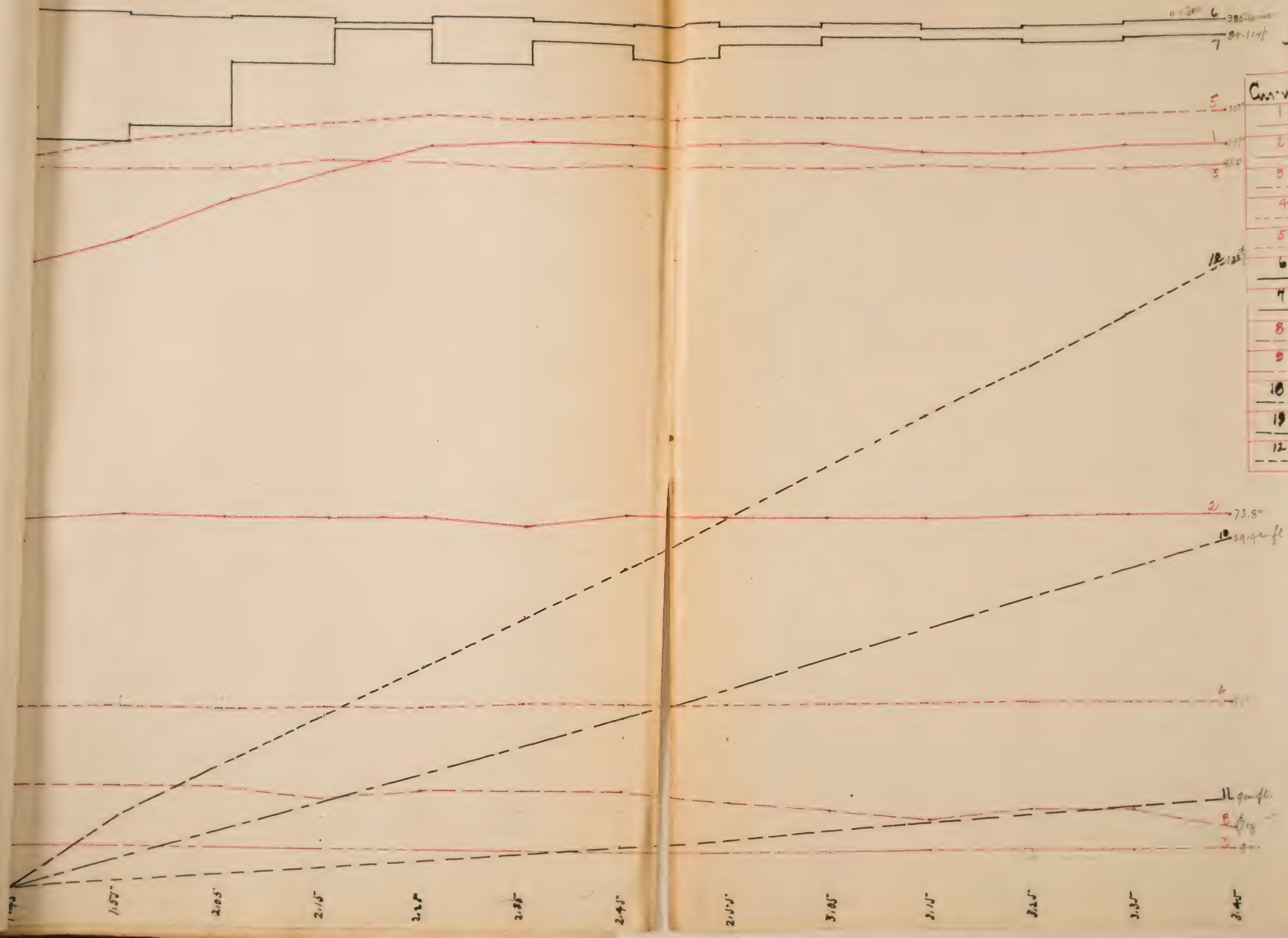
Test. No. II.

Curve	Ordinates	Scale
1	Temp. outflow water	.1" = 2°
2	Temp. inflow water	.1" = 2°
3	Temp. air	.1" = 1°
4	Temp. inlet gas	.1" = 4°
5	Temp. ex. gas	.1" = 4°
6	revolutions per min.	.1" = 1 rev.
8	Scale reading	.1" = 1 lb.
9	press. regas, inches water	.1" = 1"
7	explosions per min.	.1" = 1 exp.
10	Cu. ft. gas used (exp.)	.1" = 1 cu. ft
11	" " " (burner)	.1" = 1 cu. ft
12	lbs. water used	1" = 1 lb



Test No. III.

Curve	Ordinates	Scale
1	Temp. outflow water	.1" = 2°
2	Temp. inflow water	.1" = 2°
3	Temp air.	.1" = 1°
4	Temp. inlet gas	.1" = 4°
5	Temp. ex. gas	.1" = 4°
6	revolutions per min.	.1" = 1 rev.
7	up to 610 rs per. min.	.1" = 1 up
8	Scale reading #	.1" = 1 #
9	pressure gas, inches water	.1" = 1"
10	Cu. ft. gas used (exp)	.1" = 1 cu ft
11	" " " (burner)	.1" = 1 cu ft
12	lbs. water used	.1" = 2 lb



	- Results of Tests -	I	II	III
1	Duration of test in minutes.	130	120	120
2	No. of diagrams taken.	14	13	13
3	Mean initial pressure above atmosphere in lbs.	131.9	96.26	85.88
4	Average mean pressure during working stroke from diagram in lbs.	30.35	29.70	28.69
5	Average mean pressure during pumping stroke in lbs.	6.63	7.02	6.48
6	Revolutions per minute	403.3	371.85	385.61
7	Mean explosions per minute	139.2	118.8	81.74
8	I.H.P. net (including pumping stroke)	0.3815	0.2785	0.147
9	Load on rope brake in lbs.	1.75	1.945	0.781
10	Reading (net) of spring balance	6.20	5.438	2.510
11	Effective pull on brake (10-9)	4.45	3.493	1.729
12	Circum. of fly wheel (to centre of ropes)	6.29	6.29	6.29
13	Brake horse power.	0.3394	0.2475	0.1271
14	Mechanical efficiency of engine (%)	88.9	88.8	86.4
15	Gas used per hour (cu. ft) without ignition	22.56	14.25	17.2
16	Gas used per hour (cu. ft) ignition	7.59	4.8	4.5

~ Results of Tests ~

		I	II	III
17	Gas used (main and ignition) cu. ft per hr	30.15	19.05	21.7
18	pressure of gas at meter (in. of water)	4.25	3.8	3.94
19	Temp. of gas at meter in degrees F.	60.0	71.0	72.6
20	Gas per I.H.P. per hour in cu. ft	59.1	51.2	117.0
21	Gas per I.H.P. per hour (including ignition)	79.2	68.4	147.7
22	Gas per B.H.P. per hr. in cu. ft.	66.4	57.6	135.4
23	Gas per B.H.P. per hr (incl ignit.) in cu. ft.	88.8	76.9	170.8
24	Gas used per explosion cu. ft.	0.003645	0.00299	0.004855
25	Pounds gas used per explosion.	0.000162	0.000554	0.000968
26	Calorific value of gas per explosion calculated from analysis, B. T. U.	1.54	1.11	1.94
27	Mechanical equivalent of ditto ft. lbs.	1200.5	864.4	1510.6
28	Air used per explosion cu. ft. (calculation)	0.021395	0.02800	0.02613
29	Air used per explosion (lbs) (calculation)	0.001562	0.00139	0.001404
30	Ratio of air to gas by volume (calculation)	7.502	9.36	5.389
31	Ratio of air to gas by weight (")	20.29	25.08	14.49
32	Ratio of air to gas by weight (analysis) (check)	~	28.92	~
33	Actual net work done ft. lbs per (explo.)	90.44	77.36	59.35
34	Actual net work done B. T. U. per (explo.)	0.1162	0.0994	0.0763

	~ Results of Tests ~	I	II	III
35	Efficiency of Engine (actual)%	7.53	8.95	3.92
36	Efficiency of Engine (max. theoretical)%	15.1	11.3	7.94
37	Ratio of actual to maximum	49.8	79.2	49.4
38	Assumed temp. of gas-air after ad. to cyl. °F.	145.0	198.0	148.0
39	Calc. temp. after compression °F.	252.6	281.5	200.5
40	Calc. temp. after reaching maximum pressure °F.	1921	1493	2812
41	Amt. jacket water used per hour #.	93.6	26.12	61.87
42	Outgoing water temps.	67.4	75.1	73.1
43	Outgoing " "	139.0	192.6	142.5
44	Rise in temps. (43 - 42)	71.6	117.5	69.4
45	Mechanical equivalent of heat carried off in jacket water per explosion	634.3	338.6	681.2
46	Heat rejected in jacket water per explosion in B. T. U.	.8153	.4352	.8756
47	Heat rejected in exhaust B. T. U.	.1365	.2948	.4338
48	Heat rejected in exhaust ft. lbs. per explosion	259.77	209.83	321.39
49	Heat units not accounted for due to radiation &c. B.T.U.	.2143	.2805	.5543
50	Mechanical equivalent of the same ft. lbs. per explosion	212.54	237.83	447.35

~ Heat Balance Sheet. ~

I

Heat turned into work per explosion	0.1162 B.T.U.
Heat rejected in jacket water per exp.	0.8153 " " "
Heat rejected in exhaust per explosion	0.3655 " " "
Heat not accounted for	0.2430 " " "
	1.5400 " " "
Calorific value of gas per explosion	1.5400 " " "

II

Heat turned into work per explosion	0.0994 B.T.U
Heat rejected in jacket water per explosion	0.4352 " " "
Heat rejected in exhaust per explosion	0.2949 " " "
Heat not accounted for	0.2805 " " "
	1.1100 " " "
Calorific value of gas per explosion	1.1100 " " "

III

Heat turned into work per explosion	0.0763 B.T.U.
Heat rejected in jacket water per exp.	0.8756 " " "
Heat rejected in exhaust per explosion	0.4338 " " "
Heat not accounted for	0.5543 " " "
	1.9400 " " "
Calorific value of gas per explosion.	1.9400 " " "

Analysis of Gas. I

	% Vol.	% Wt.	C_p in 1# of gas	C_v in 1# of gas	Calorific value in 1# gas.
C_2H_4	4.6	11.9	0.0481	0.0395	2523
CH_4	34.9	51.8	0.3070	0.242	12017
CO	7.2	18.2	0.04580	0.0324	804
O	1.0	3.2	0.00658	0.00426	~
H	50.3	2.33	0.3187	0.2249	4898
N	2.0	5.2	0.0127	0.0089	~
CO_2	0.0	0.0	~	~	~
total	100.0	100.0	0.7388	0.55345	20,242 B.T.U.

II & III

C_2H_4	4.2	12.5	0.04868	0.0400	2555
CH_4	35.2	51.56	0.3055	0.2404	11962
CO	7.0	17.94	0.04395	0.03105	771
O	1.1	3.22	0.00699	0.00499	~
H	49.6	2.08	0.3095	0.2183	4262
N	2.4	6.15	0.0150	0.01065	~
CO_2	0.0	0.0	~	~	~
	100.0	100.0	0.72962	0.645392	20,055 B.T.U.

Analysis of Exhaust Gases.

I

	% Vol.	% Wt.	C_p in 1# of gas.	C_v in 1# of gas.
CO_2	5.2	7.93	1.712	1.358
O	0.175	0.19	0.041	0.029
CO	0.2	0.19	0.046	0.032
N	94.425	91.69	22.391	15.861
total	100.	100.	24.19	17.28

II

	% Vol.	% Wt.	C_p in 1# of gas.	C_v in 1# of gas
CO_2	3.47	5.34	1.137	0.951
O	0.50	0.56	0.122	0.087
CO	1.93	1.89	0.464	0.327
N	94.10	92.21	22.510	15.950
total	100.	100.	24.233	17.315

I. $(C_p - C_v)\,7.78 = R$ in ft lbs.

$(24.19 - 17.28)\,7.78 = 53.7$

II $(24.233 - 17.315)\,7.78 = 53.82$

Analysis of Exhaust Gases.

III

	% Vol.	% Wt.	C_p # in gas	C_v # in gas
CO_2	3.60	5.54	0.01197	0.00947
O	0.77	0.86	0.00186	0.00133
CO	1.76	1.73	0.00424	0.00299
N	93.87	91.87	0.2242	0.15890
total	100.	100.	0.24227	0.17269

$(C_p - C_v)\,778 = R$ in ft. lbs.

$(0.24227 - 0.17269)\,778 = 54.13 = R$

$n = \frac{C_p}{C_v} = 1.405$

Sample Cards.

I

II.

Length = 8.71"
Area = 1.58 □"
Pw = 24.3 #

11

Length = 8.72"
Area = 1.72 □"
Pw = 27.7 #

at 21

Length = 8.70"
Area = 1.76 □"
Pw = 28.6

at 21

Length = 8.72"
Area = 1.84 □"
Pw = 29.7

III.

Length = 3.71"
Area = 1.12 sq in
Pmax = 38.6 #

Length = 1.50
Area = 1.08 sq in
Pmax = 32.4 #

Length = 3.16"
Area = 0.78 sq in
Pmax = 25.1 #

Length = 3.69"
Area = 0.74 sq in
Pmax = 24.0 #

3 1198 03072 7908
N/1198/03072/7908X

3 1198 03072 7908
N/1198/03072/7908X